Fuel Efficiency Booklet

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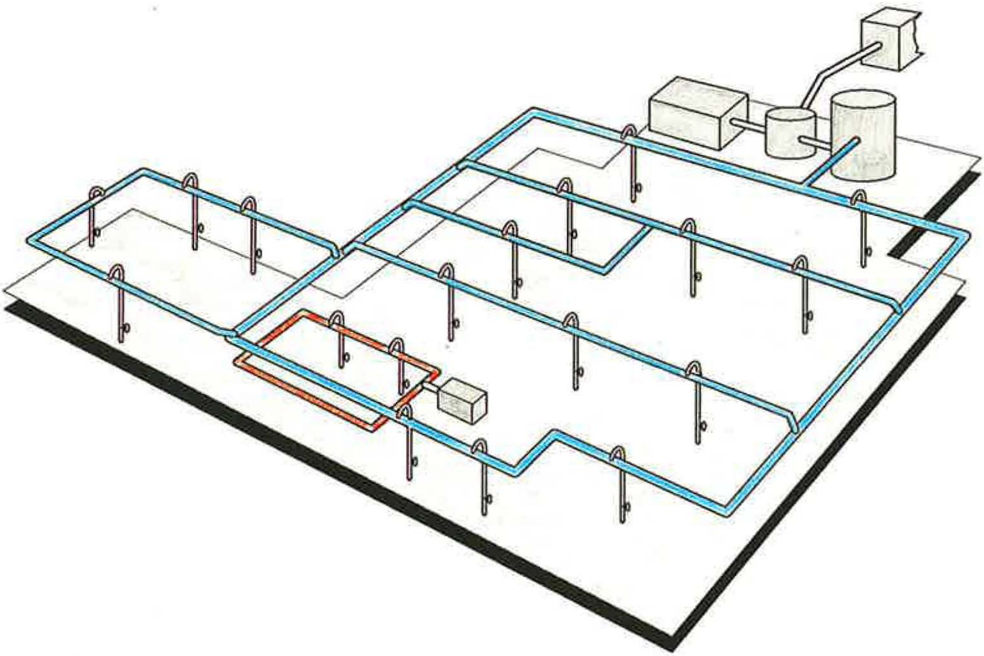
Compressed Air and Energy Use



BEST PRACTICE PROGRAMME

Energy Efficiency Office
DEPARTMENT OF THE ENVIRONMENT

BEST PRACTICE PROGRAMME

Compressed air and energy use

Contents

1. Introduction

This booklet has been written to help those responsible for energy management and the maintenance of services in buildings, factories, process plant and garages to obtain a better understanding of how to apply air compression systems correctly, thereby preventing the waste and misuse of compressed air.

Approximately 10% of the total electrical power consumed by industry is used to generate compressed air. Over a ten year period the total cost of compressed air comprises 75% energy, 15% capital and 10% maintenance. Therefore an energy efficient system will be the most cost effective.

The versatility, flexibility and safety of compressed air as an energy transmitting medium ensures its continued use as an essential service. However, compressed air can be very expensive to generate and usually offers excellent potential for savings.

In order to show savings in perspective, reference is made throughout this booklet to an example installation at a factory with a demand for 500 l/s (1,000 cfm) of compressed air at 7 bar, operating on a 48 hour week with power costs of 4.5p/kWh. The example installation produces compressed air at a cost of £4,020 per 100 l/s (200 cfm) per annum. The factory will therefore spend £20,100 per annum on electricity to generate compressed air. It is usually possible to save 10% - 20% of these costs with very little capital outlay, simply by improved management of the system. This order of savings makes a very worthwhile contribution to overall cost and energy saving.

This booklet gives advice on practical methods of ensuring that costs are kept to a minimum and that savings are realised wherever possible. Obtaining savings should be approached in a structured manner, examining each of the main areas sequentially. These areas are:

- Leaks
- Use/misuse
- Distribution
- Treatment
- Generation

Most air compressors are used for 7 bar gauge (100 psig) duties, and all the information in this booklet refers to this pressure level, although much of the information is relevant whatever the operating pressure. All pressures in this booklet are gauge pressures. Electric motors are used to drive over 95% of compressors in industry. This booklet therefore refers to these types of driver, although other drivers, such as steam turbines, diesel and gas engines, are used.

2. Leaks

This subject, which comes under the general heading of misuse, is treated on its own in this booklet because it is the single, biggest waste area and yet one of the simplest and cheapest to control and obtain savings. A system with 5% of demand as leaks is said to be excellent and one with 10% is good. Systems with leaks as high as 70% of demand have been measured and 30% is not unusual.

The first action necessary is to take measurements to establish the leakage rate, for which several methods exist.

The best method is to install a flow meter and pressure transducer in the compressor feeding main, after the receiver. The outputs of both should be fed to a chart recorder and readings taken over a representative period.

If this method is not practical, a fairly accurate way is to pump the system up to normal operating pressure during non-productive hours using a compressor of known capacity. Providing that the compressor has a greater capacity than the leakage rate, it will unload at the operating pressure. If it does not an additional machine will need to be put on line. As the system pressure drops due to leakage the compressor will load at its minimum running pressure. Taking the average loaded and unloaded times over a representative period will enable an estimation of the leakage rate to be calculated.

If the example 500 l/s (1,000 cfm) system has a leakage rate of 20%, the annual cost will be £4,020 to satisfy the leaks. Reducing the leakage to 10% will save over £2,000 per annum for very little or no capital outlay.

Having established the size of the leakage problem, an aggressive campaign of leak reduction should take place. Targets should be set and careful monitoring of results conducted.

This work will involve inspections during silent hours checking for pipework and tool leaks, and checking hoses and couplings for air tightness. Following this programme the leakage rate should be remeasured and the work continued until the target is met.

This is an ongoing exercise which must be repeated at least every six months otherwise the problem will return.

3. Use/Misuse

3.1 Areas of misuse

Compressed air is heavily misused in industry. Careful thought should be given to all uses to see whether another, more cost-effective, method might be used instead of compressed air.

For example, at a Steelworks, measurements found an average air demand of 5,000 l/s at 7 bar. After investigation, it was established that only 2,000 l/s were actually being used appropriately, 2,000 l/s were actually used at 3 bar and 1,000 l/s were used for non-compressed air duties such as water-jetting and bearing cooling.

Another common malpractice is to generate compressed air at times when it is not needed. In many cases there is no need for compressed air at all during non-production hours, but compressors are often not switched off.

3.2 Potential savings from use/misuse

Compressed air generated at 7 bar should not be used for low pressure duties. If the demand is large enough, it is worthwhile generating air at a lower pressure. Typically a 3 bar compressor will generate at 257 J/l *, a 33% saving over generating at 7 bar.

Typical examples of wasteful use of 7 bar air are:

- Air knives
- Blow guns (recommended by H&SE to be regulated to 2 bar)
- Air lances
- Air agitation
- Air jets to eject products from high-speed production machines (air entraining venturi nozzles are excellent energy saving devices for the air jet applications)
- Some powder transfer

At times, a higher pressure is required for special machines perhaps 10 bar, and all the air is generated at this pressure. This is a misuse and a small high pressure machine or booster compressor should be installed.

All these uses should be considered as part of an energy saving campaign.

4. Distribution

4.1 General

Following compression and treatment, compressed air is distributed to the usage points by a piping network. Much energy can be wasted during distribution by having to generate overpressure to overcome incorrect pipe, valve and other air line component sizing which cause high flow velocities and pressure drops.

All systems should be designed to minimise pressure drops.

Examples of the energy wasted by the use of small bore pipe are given in Table 1. This table shows the pressure drop and power losses per 100 metres of air main with a 250 l/s, 7 bar compressed air demand.

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* Efficiencies are measured in specific power consumption (joules/litre (J/l))

Table 1 Energy wasted in small bore pipes		
Pipe Nominal Bore (mm)	Pressure drop per 100m (bar)	Equivalent power lost (kW)
40	1.8	9.5
50	0.65	4.4
65	0.22	1.2
80	0.04	0.2
100	0.02	0.1

4.2 Potential savings in distribution

It is worthwhile obtaining a flow/pressure profile of the distribution network to establish where the bottlenecks occur and how they can be overcome.

1 *Configuration*

Ring main and grid systems are preferable to feeding spurs, as they help to balance the pressure around the system.

2 *Sizing*

Air velocities should not exceed 6 metres per second in the main components of a distribution system. The distribution system should be designed to cause no more than 0.1 - 0.2 bar pressure drop at full demand at the usage points.

The nomograph shown in Fig 1 is a very useful method of arriving at pipe sizes.

In conjunction with establishing the correct pipe diameters for the flow, a check on the pressure drops caused by the major valves and fittings should be made. Table 2 gives the equivalent pipe length for these components at the relative nominal pipe diameter. The equivalent lengths should be added to the actual pipe length to be used, and the total length should then be used with the nomograph shown in Fig 1 for finalising the pipe diameter.

3 *Maintenance*

Piping systems need regular inspection and maintenance. Inspection for leaks (covered in Section 2), checking drains and blowing down contamination, are all worthwhile measures to avoid energy losses.

4 *System isolation*

Whilst it is sometimes necessary to keep parts of a distribution network pressurised at all times, some areas, for example an assembly department, can be isolated during non-productive hours to prevent wastage due to leakage or misuse. Manually or electronically operated zone isolation valves can be installed in the distribution network to shut off at properly arranged times.

5. Treatment

5.1 Background

Most compressed air users need higher quality air than that delivered by the compressor.

The desired air quality in terms of dirt, water, oil and microbial burden is achieved by treatment after compression. The higher the quality specified, the greater the energy consumed by the treatment system, and the higher the additional generation pressure needed to overcome losses during treatment.

Treatment systems range from a simple aftercooler, which is nearly always supplied with the compressor package, through to filters and refrigerated, sorption, deliquescent and desiccant dryers. There are many variations of each system; some are more energy efficient than others.

Table 3 shows the ISO/DIS 8573.1 standard for delivered air quality.

The requirement for high quality compressed air is increasing all the time as production methods become more sophisticated.

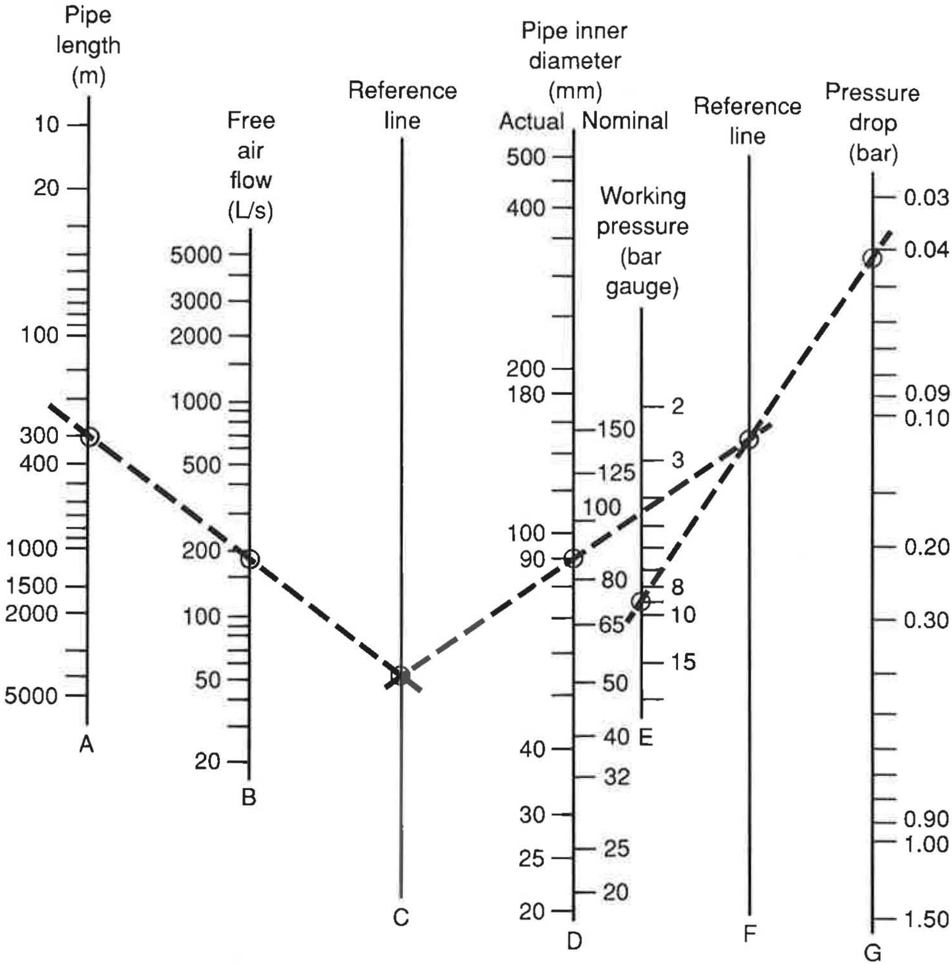

Fig 1 Nomograph

Table 4 gives information on typical application classes required; there are many more applications and combinations in practice. For certain applications more than one class can be considered. This subject is under review, and therefore Table 4 should be used for guidance purposes only.

5.2 Potential saving areas - air treatment

It can be seen that there is a very wide range of requirements for air quality. It is most important to install the right equipment for the duty, and equally important to minimise energy requirements. Much energy can be expended on unnecessary levels of treatment.

Many plants only need part of the air treated to very high quality. In these cases, excellent savings are achievable by treating all the generated air to the minimum acceptable level, and improving the quality to the desired level close to the usage point.

Table 2 Pressure loss through steel fittings										
Item	Equivalent pipe lengths in metres									
	Inner pipe diameter (mm)									
	15	20	25	40	50	80	100	125	150	200
Gate valve Fully open	0.1	0.2	0.3	0.5	0.6	1.0	1.3	1.6	1.9	2.6
Gate valve Half closed		3.2	5	8	10	16	20	25	30	40
Diaphragm valve Fully open	0.6	1.0	1.5	2.5	3	4.5	6	8	10	
Angle valve Fully open	1.5	2.6	4	6	7	12	13	18	22	30
Globe valve Fully open	2.7	4.8	7.5	12	15	24	30	38	45	60
Ball valve (full bore) Fully open	0.5	0.2	0.2	0.4	0.3	0.4	0.3	0.5	0.6	0.6
Ball valve (reduced bore) Fully open	3.4	4.9	2.4	2.2	5	2.6	4.1	3.3	12.1	22.3
Swing check valve Fully open		1.3	2.0	3.2	4	6.4	8	10	12	16
Bend R = 2d	0.1	0.2	0.3	0.5	0.6	1.0	1.2	1.5	1.8	2.4
Bend R = d	0.2	0.3	0.4	0.6	0.8	1.3	1.6	2	2.4	3.2
Mitre bend 90°	0.6	1.0	1.5	2.4	3	4.8	6	7.5	9	12
Run of tee	0.6	0.3	0.5	0.8	1.0	1.6	2	2.5	3	4
Side outlet tee		1.0	1.5	2.4	3	4.8	6	7.5	9	12
Reducer		0.3	0.5	0.7	1.0	2	2.5	3.1	3.6	4.8

Table 3 Air quality classifications ISO/DIS 8573.1				
QUALITY CLASS	DIRT Particle size (micron)	DIRT Concentration (mg/m^3)	WATER Pressure dewpoint (°C (ppm vol) at 7 bar)	OIL (including vapour) (mg/m^3)
1	0.1	0.1	-70 (0.3)	0.01
2	1	1	-40 (16)	0.1
3	5	5	-20 (128)	1
4	15	8	+3 (940)	5
5	40	10	+7 (1240)	25
6	-	-	+10 (1500)	N/A
7	-	-	No Spec	N/A

Table 4 Typical air quality			
	Typical classes		
Application classes	Oil	Dirt	Water
Air agitation	3	5	3
Air bearings	2	2	3
Air gauging	2	3	3
Air motors	4	4	5
Brick and glass machines	4	4	5
Cleaning of machine parts	4	4	4
Construction	4	5	5
Conveying, granular products	3	4	3
Conveying, powder products	2	3	2
Fluidics, power circuits	4	4	4
Fluidics, sensors	2	2	2
Foundry machines	4	4	5
Food and beverages	2	3	1
Hand operated air tools	4	5	5
Machine tools	4	3	5
Mining	4	5	5
Micro-electronics manufacture	1	1	1
Packaging and textile machines	4	3	3
Photographic film processing	1	1	1
Pneumatic cylinders	3	3	5
Pneumatic tools	4	4	4
Process control instruments	2	2	3
Paint spraying	3	3	3
Sand blasting	-	3	3
Welding machines	4	4	5
General workshop air	4	4	5

A good example of this would be a car production plant where 70% of the requirement is for 4.4.2 quality air, which can be supplied by a refrigeration dryer and oil removal filter. The energy requirement of a refrigeration dryer is much less than that of a desiccant dryer, and the pressure drop across the filter will be 0.2 bar. 30% of the air is required at 1.2.1 quality, for the special requirement of the paint and engine assembly areas. The desiccant dryers and special filtration needed for this quality can be installed in the usage areas. Energy cost savings of around £2,000 per annum for every 500 l/s (1,000 cfm) delivered can be achieved by only treating to required levels. In addition, savings will be achieved from reduced dryer maintenance and consumables, such as filter elements and desiccant replacement.

1 *Configuration*

Air dryers typically take the air being delivered by the compressor aftercooler at a maximum temperature of 35°C.

For class 1.1.1 quality air, a heated or heatless twin tower desiccant dryer with special desiccant and drying cycle is required. Oil , water and dust removal filters and an activated carbon absorber unit will also be required.

This system consumes a lot of energy, requiring up to 15% of the compressed air or the electrical equivalent for desiccant regeneration, and there is a pressure drop of up to 1.5 bar across the filters, when in service, which will require additional generation pressure.

The type of compressor used is important. An oil-free machine could save one stage of filtration compared with using an oil-injected compressor. For high quality air requirements, it is recommended that an oil-free machine is purchased wherever possible. In addition to the treatment savings, further benefits of efficiency and longevity are gained and there is no chance of compressor oil contaminating the desiccant.

When oil-free machines are used in heavily polluted atmospheres it may be necessary to use oil removal filtration.

In the example installation, the 500 l/s (1,000 cfm) compressor incurs costs of £20,100 per annum when delivering aftercooled air. To supply 1.1.1 quality air, additional costs of £4,220 (21%) per annum would be incurred, due to the treatment devices.

As the requirement for air quality becomes less intense than 1.1.1, the additional energy requirement is reduced. Air of quality 2.2.1, where a lower specification desiccant dryer (heated, heatless or with external blower regeneration) performing at -40°C pressure dew point can be used, would cost around 15% more than delivering aftercooled air.

Air of 2.3.1 quality can be provided using a special sorption dryer and an oil-free compressor. The drum in this dryer is impregnated with the drying medium and is slowly rotated by a very small motor. Compressed air is fed through a sealed segment of the drum and is dried within a range of -15°C to -40°C, depending on the compressor load. Hot air ducted from before the machine aftercooler is used to regenerate the drying medium in the part of the drum which is not being used to dry the air, utilising the waste heat of compression for regeneration. To provide 2.3.1 quality air by this method, with an oil-free compressor and limited filtration, would typically cost 3% more than delivering aftercooled air.

Compressed air of 4.4.5 quality can be provided from any compressor configuration by use of a refrigerated dryer and limited filtration. The extra cost will typically be 5% more than that of delivering standard aftercooled air.

2 *Maintenance*

The pressure drop across all filter elements in service will increase with time, due to fouling and blinding, calling for a higher generation pressure and additional energy to deliver the required demand. It is most important to minimise pressure drops. All filters should be fitted with differential pressure gauges which should be regularly calibrated.

With all dryers, particularly desiccant types, the dewpoint should be checked regularly. Many are found to be operating well below specification, although they will continue to consume energy at the same rate as that needed for design dewpoint performance.

3 *Condensate*

Condensate occurs as a natural by-product of compressing and cooling air. By-passed traps, or slightly opened drain valves, are found at many sites and often account for over 10% of the total compressed air demand. Wet air causes maintenance and reliability problems and product spoilage. Old, poorly maintained traps work badly, if at all, especially when emulsified oil and water mixtures, pipescale and rust are present. If no maintenance is carried out, these traps will be by-passed.

Electronically operated traps are now available, which sense the level of condensate that has been collected by change in capacitance. At high levels the condensate is ejected; at low levels the trap closes, preventing loss of compressed air. Wherever possible, modern, reliable condensate traps should be installed.

4 *Control*

Refrigerated dryers are available in several configurations depending on the duty, and although they are designed for full throughput, some means of part load control should be fitted. Some types have a thermal mass which is held at the correct temperature, whilst others have step unloading and hot gas by-pass valves which enable the unit to match the load.

Desiccant dryers should be equipped with a reliable dewpoint sensing arrangement, which will automatically vary the regeneration cycle, saving energy when the load is less than design.

5 *Sizing*

Ideally, each compressor should have a dedicated dryer for control and reliability purposes. This is not always practical, due to capital cost and space availability. All configurations are very reliable if well installed and maintained. If a dryer for each compressor is not practical, a unit suitable for 100% duty is recommended to give the best energy and air quality performance.

Multiple units are often installed and piped in parallel with wet and dry air manifolds. In these cases, pressure trimming valves or sonic nozzles should be fitted to each dryer so that it can be properly set up for the duty. This will also avoid preferential flow, which causes air quality and pressure drop problems.

Filters should be adequately sized for the duty. If the filter connections are considerably smaller than correctly sized pipework, they will cause pressure drop problems. It is better to pay more at the outset and thereby avoid pressure drop and energy wastage.

6 *Installation*

Dryers should be installed in well-ventilated areas. For continuous processes, all filters should be duplexed with changeover valves for ease of maintenance. A dryer by-pass should also be installed for emergency maintenance; this must be locked off during normal running to prevent accidental operation which would contaminate the dry air main.

6. Compressed air generation

6.1 Compressor configurations

Air compressors are available in many configurations. In general, the choice of compressor and aftertreatment system is dictated by:

- the capacity and pressure required;
- the capital funds available;
- the specified delivered air quality requirements.

The relative generation efficiencies of different compressor configurations are summarised in Table 5.

There is a considerable variation in specific energy consumption between configurations. Another consideration is the ability of a compressor to operate efficiently on part load.

Many piston compressors are still in use. However, over the last decade there has been a strong trend towards rotary vane, screw and centrifugal compressors for new installations, because these machines are simpler to maintain and install, and quieter to run. Rotary machines are not necessarily more efficient than well maintained large piston compressors, but by use

of waste heat recovery, which is normally simple with rotary vane and screw machines, any efficiency deficit can be recovered.

Capacities of 2.5 to 25 l/s (5 - 50 cfm) are served by compressors of the single or two stage air cooled piston configuration which are usually receiver mounted, or by single stage oil-injected rotary vane or screw compressors. It is possible to obtain non-lubricated piston compressors for duties such as food, air-conditioning and pharmaceutical production, although for these applications it is usual to use filtration to remove the oil carried over from the compressor.

Capacities of 25 to 250 l/s (50 to 500 cfm) are met by single stage oil injected rotary vane or screw compressors. For oil-free applications, the two stage rotary toothed rotor compressor or non-lubricated screw compressor are available; however, many users who need high quality air employ filtration on oil injected machines, because there is a saving in the capital cost of the machinery.

For capacities of 250 to 1,000 l/s (500 to 2,000 cfm) it is still possible to purchase double acting water-cooled piston compressors, either in lubricated or non-lubricated form, although they are becoming less popular. In this capacity range, single stage oil-injected compressors are available for standard air quality duties. Oil-free duties can be served by piston compressors with special carbon or teflon wearing surfaces, by two stage oil-free rotary screw compressors or by multi-stage centrifugal compressors.

Capacities of 1,000 to 2,000 l/s (2,000 to 4,000 cfm) are met with two stage oil-free rotary screw compressors or multi-stage centrifugal types, both of which are inherently oil-free.

Over 2,000 l/s (4,000 cfm) the multi-stage oil-free centrifugal compressor serves the market place until very large mass flow compressors of the axial flow configuration come into consideration.

The specific power figures have been obtained from actual field test results according to BS 1571 Part 2: 1984. These take into account electric drive motor inefficiencies and are a true assessment of the actual electrical input, not shaft input power which is usually stated by manufacturers.

Table 5 Summary of compressor configurations with relative efficiencies

Description	Capacity (l/s)	Specific power (J/l)*	Part Load efficiency**
Lubricated piston	2 - 25 25 - 250 250 - 1,000	510 425 361	Good Good Excellent
Non -lubricated piston	2 - 25 25 - 250 250 - 1,000	552 467 404	Good Good Excellent
Oil-injected vane/screw	2 - 25 25 - 250 250 - 1,000	510 446 404	Poor Fair Fair
Non-lubricated toothed rotor/screw	25 - 250 250 - 1,000 1,000 - 2,000	429 382 382	Good Good Good
Non-lubricated centrifugal	250 - 1,000 1,000 - 2,000 Above 2,000	446 382 361	Good Excellent Excellent

* 1 J/l ≈ 21 kW/100 cfm

** Efficiencies are measured in specific power consumption (joules/litre (J/l)).

6.2 Potential saving areas - generation

1 *Configuration*

It can be seen from Table 5 that generation efficiencies vary between compressor configurations. Savings can be made by changing to the most efficient type for the duty, although this would involve high capital expenditure in the case of an existing factory. In the case of new plant it is often worthwhile spending additional capital to obtain the best possible generation economics. Over the long term, additional first cost is often paid back out of lower running and maintenance costs. In addition, the most efficient machines are usually the most reliable.

2 *Maintenance*

Compressors run for many hours, often in appalling conditions. Good maintenance is therefore of the utmost importance. Piston compressors, particularly the oil-free variant, suffer the most in efficiency terms from lack of maintenance. For the example installation, a poorly maintained oil-free piston compressor serving the 500 l/s (1,000 cfm) demand would deteriorate in efficiency from 400 J/l to 450 J/l over a 12 month period, adding over £2,000 to the annual running costs.

Rotary vane and screw machines do not fall off in efficiency so rapidly; however, there is a finite life for such compressors. As a guide, this type of machine must receive major maintenance after 25,000 hours life to maintain good efficiency. Oil-free toothed rotor and screw machines perform well for periods of up to 40,000 hours, after which there is a slow fall off in efficiency due to gradually increasing internal clearances.

Centrifugal compressors, having few moving parts and comparatively large 'as built' clearances, will maintain their efficiency over longer periods, but it is essential that the inlet air filters, cooling water system and the intercoolers are rigorously maintained otherwise efficiency will fall off rapidly.

It is a false economy to ignore maintenance on any type of compressor. It is recommended that manufacturers, or their accredited agents, are used for service work and that genuine spare parts, to the original design, are used. An apparently cheaper component, such as a non-genuine discharge valve, costs more in the long term due to the detrimental effect that it has on the compressor efficiency.

Fig 2 shows in bar chart format how a typical group of 500 l/s lubricated piston compressors vary in efficiency whilst running at site. Machine 4 would have recently been overhauled; the other units are in need of maintenance. Completion of maintenance would result in annual savings of £14,300 when the duty is for full output over a 48 hour week.

3 *Condition assessment*

The running condition of a compressor can be assessed fairly easily. Table 6 summarises the measurements required for different types of compressor.

4 *Condition monitoring*

Most modern compressors have excellent electronic monitoring systems which automatically log their running condition, generate alarms when abnormal running conditions occur and ultimately shut the machines down before any damage occurs.

It is possible to purchase similar monitoring units for retro-fitting to existing compressors. This is particularly worthwhile with two-stage water-cooled piston compressors where compressor running condition has a major effect on efficiency. Adequate maintenance skills are not readily available in many factories making early warning of problems essential.

5 *Power factor correction*

Correcting the compressor drive motor power factor is an inexpensive and effective way of reducing the kW dissipated relative to the kVA applied, possibly enabling reduction of the tariff.

6 *Soft starters*

Soft start controls are available which provide a variable start time with minimised starting currents, and which eliminate current surges thereby preventing motor damage.

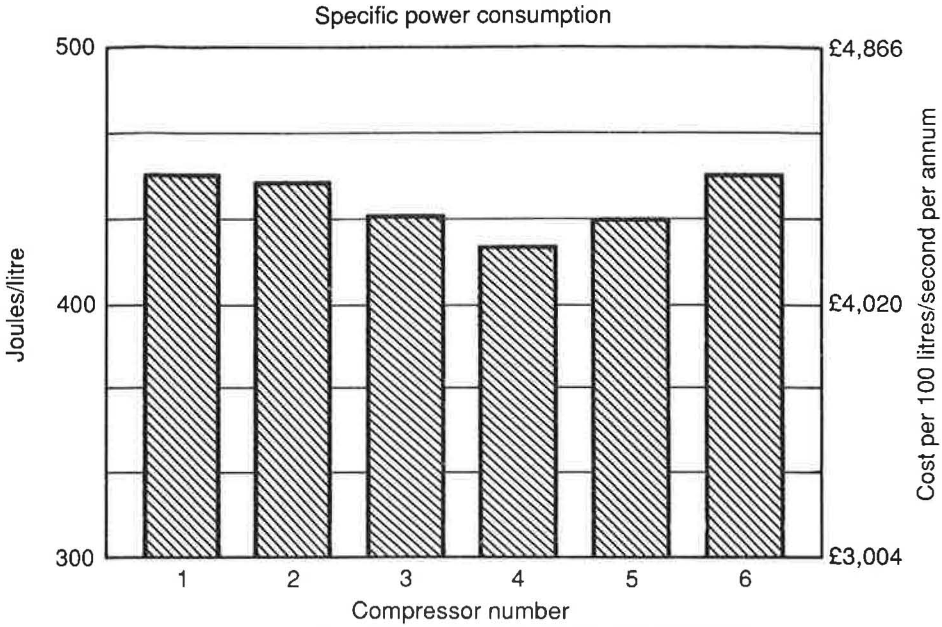

Fig 2 Typical specific power consumption of compressors

Table 6 Compressor assessment		
Compressor Type	**Measurement***	**Indication**
All types	Air discharge temperature downstream of the aftercooler, or cooling water temperature for water-cooled machines.	Over 15°C difference shows cooling surfaces are becoming fouled and efficiency is falling off.
	Inlet filter differential pressure. **	Values outside manufacturer's specification can indicate fouled inlet filters, leading to efficiency loss.
Two-stage piston, toothed rotor or screw types	Intercooler pressure	Measurement outside that in manufacturer's service manual indicates problem.
Oil-injected vane or screw types	Difference between compressor element discharge pressure and actual delivered pressure.	Greater than 0.3 bar pressure differential indicates problems with oil separator and loss of efficiency.
Centrifugal types	Interstage temperatures and pressures, pinion vibration levels and air inlet differential pressure.	Values outside manufacturer's specification indicate problems. Machine not in optimum running condition.

* All the pressure and temperature gauges used for this purpose must be regularly calibrated.

** Most compressors have an inlet filter differential pressure gauge fitted: if not, it is recommended that one is fitted.

7 *Reduction in generation pressure*

Many systems run at pressure levels well above those required at the usage point. Sometimes during non-productive hours the system is kept pressurised for essential control items, which often require lower pressures than the production equipment.

Generation of overpressure is often necessary to overcome air treatment systems (see Section 5.1) or system bottlenecks (see Section 4.2), when the usage points are already at the minimum acceptable pressure. If neither of these cases apply, the plant engineer should slowly reduce the compressor generating pressure until the minimum operating pressure is established; the delivered pressure should be increased by 0.2 bar to provide a safety margin. Reduction of generating pressure results in considerable savings; for example, a reduction from 7 bar to 6 bar will give a saving of 4% in generation costs.

Additional savings accrue from pressure reduction. The consumption of most air using devices, such as air tools, spray guns and air knives, is proportional to the absolute operating pressure ratio. Therefore a reduction in pressure down to the minimum acceptable operating pressure of the using devices will save both air and energy. For example, a 6 mm nozzle will consume 43.32 l/s (87 cfm) at 7 bar and 37.82 l/s (75 cfm) at 6 bar, a reduction in air consumption of 14.5%.

At the example 500 l/s (1,000 cfm) installation, reducing generating overpressure and device operating pressure from 7 bar to 6 bar would result in annual savings of over £3,500.

Reduction in generation pressure during non-productive hours will require some form of automatic control; however, the costs incurred will be recouped quickly.

8 *Compressor running strategy*

Compressors vary in efficiency and controllability, even those of the same configuration, size and manufacturer. Testing each compressor to BS 1571 Part 2: 1984 prior to delivery or at site will establish its efficiency and part load running costs. The results will enable an operating strategy to be devised which ensures that the best available machines for the duty are on-line.

9 *Sizing*

Compressors should be sized as closely as possible to the demand. It is not economical to run any machine for long periods at low loads due to electric motor inefficiencies. The off-load power can be 15% - 70% of the on-load power once motor inefficiencies have been taken into account.

For new installations with multiple compressors, it is worthwhile considering installing a selection of unit sizes, so that the demand can be met by compressors operating close to full output. Smaller machines should have efficiencies equal to those of the larger units, otherwise the object of the exercise will have been defeated.

10 *Control*

This is an area where very considerable energy savings can be made. For relatively low capital outlay, a modern control system can save 5% - 20% of the total generation costs. Many type of standard compressor controls are available; some of these are discussed below.

Firstly the hours when compressed air is actually required should be identified. In many cases compressors run unnecessarily - significant savings can be made by simply turning them off, either manually or by use of an automatic timing device. Automatic timers are usually a component of more sophisticated control systems. Care must be taken not to deprive and essential control equipment of compressed air.

Variable speed drive (VSD) motors, driving piston and screw compressors, offer many advantages in terms of control and efficiency. To-date the costs have been prohibitive; however, new advances in electronics and control gear are making these systems more popular. Care should be taken not to reduce the compressor speed to the extent that it is inadequately lubricated. VSD motors are not suitable for centrifugal compressors.

Piston machines with two- or three-step inlet suction valve unloaders, on- or off-line inlet valves or five-step clearance pocket unloading, give the best efficiencies at part loads. Piston,

vane and screw machines with variable inlet throttle valves that modulate over a close pressure range are not efficient on low loads, because they are positive displacement machines and throttling causes an increase in compression ratio.

Rotary screw machines are often fitted with both two-step unloading and modulating control, with a hand operated or automatic change over switch. Modulation should only be used if the load is over 75%: below this, two-step unloading is more efficient. Two-step systems on any machine operate over a pressure differential of around 0.5 bar between full and no load. It is necessary to install a correctly sized air receiver to avoid control hunting.

Centrifugal compressors are dynamic machines, and behave efficiently on part load within their performance envelope. Output is normally reduced by modulation to 70% of the design flow. For installations where the demand is likely to be less than this at times, machines with automatic dual control systems should be installed to avoid wasting energy due to by-passing of pressurised air at part loads. Inlet guide vanes are preferable to inlet throttles, because they improve the part load efficiency and turn-down range, particularly in off-design inlet conditions.

Most compressors up to 1,000 l/s (2,000 cfm) have the facility to be switched to automatic stop/start control; some machines will change to this mode automatically. This feature stops the machine after a prolonged period of no load running, usually 10 - 15 minutes, if there has been no further demand for air. The machine will automatically restart once there is a demand for air. The off-load running time is essential, unless a soft starter is fitted, to protect the drive motor from too many starts.

Various forms of automatic sequencing control exist for optimising best running of multiple compressor installations and equalisation of wear through rotation of the running sequence.

Microprocessor-based systems have much more accurate pressure control than either pressure switch or air governor controls. They can take into account lower pressure requirements during non-productive hours (see Section 2.2 point 7) and adjust accordingly, and can also control system isolation valves (see Section 4.1 point 4).

One computer-based system currently available saves energy by reducing the period of time that machines in a multiple installation are running off-load. This is achieved by predictive switching which shuts a machine down immediately it goes off-load. When the demand increases, the next available machine in the rotational sequence will start, enabling the first to remain off and eliminating the need for no load running. The system will also select the most suitable number and sizes of compressors in a multiple installation to meet the demand. The microprocessor learns about the system demand pattern and takes control actions to ensure that the demand is met with the lowest possible energy costs.

Control systems can be integrated with building management systems along with compressor condition monitoring, automatic operation of zone isolation valves, compressor electric motor input readings and departmental air demand metering from remote outstations.

11 *Pre-cooling*

Benefits in energy consumption, air quality and delivered air volume can be gained by pre-cooling the inlet air by refrigeration. Pre-cooling is particularly worthwhile on low pressure blowers and single stage compressors; the advantages are not so noticeable on multi-stage machines. It is not recommended for centrifugal machines; although flow would be increased, the machine would be operating a long way from design conditions and would be inefficient.

Great care must be taken to ensure the inlet air temperature is not reduced below the minimum acceptable value specified by the compressor manufacturer, in order to avoid material problems within the machine and overloading of the main drive motor.

Compression of dry chilled air results in:

- no water in the compression spaces;
- elimination of the dust which is present at the inlet, due to its entrainment in ice formed during the refrigeration process;

- unit cost savings, because the cold dense inlet air drawn in by the compressor produces additional output;
- energy savings, by removing the need for conventional drying and some filtration equipment on many systems.

It has been demonstrated that pre-cooling can save up to 25% of the energy costs in some installations.

12 *Delivering hot air*

Some processes, such as drop forging hammers, benefit from hot compressed air. To prevent air cooling:

- the compressor should not be aftercooled;
- all the air pipework should be lagged.

In addition, an over-sized condensate recovery system should be fitted to take care of the additional condensate which will form. If the air is kept hot up to the usage point, the volumetric increase achieved by this method will save some 10% of the energy consumption.

A more refined compressed air re-heat system uses an air-to-air heat exchanger to reheat aftercooled air, utilising the waste heat of compression in the air after it leaves the compressor and before it enters the aftercooler.

The heat from the hot wet air increases the volume of the aftercooled air from which the condensate has been removed. The hot wet air is then fed to the aftercooler and the process continues. The pipework up to the usage points must be lagged to maintain the temperature and the volumetric gain. This method of recovering the waste heat of compression removes all condensate, unless the delivered air temperature drops to below the aftercooler outlet temperature.

Air reheaters can be used to achieve volumetric gain. If this method is adopted, care must be taken to ensure that any risk of ignition from compressor oil carry over is eliminated.

13 *Receivers*

Manufacturers normally recommend receivers with a minimum volume of 10% of the installed compressor output delivered in one minute.

Additional receiver capacity can be useful in meeting short peak demands, which would otherwise cause pressure drops unless a larger size compressor is installed. Receivers installed at remote parts of the distribution system, near heavy demand users, help to balance the system pressure and avoid pressure drops.

14 *Location*

Compressors can either be installed in a central compressor house or at individual locations depending on the duty.

Modern rotary machines with low noise levels lend themselves to dispersed locations, which can be useful in keeping distribution pipework to a minimum, meeting heavy demands at the usage point and providing local space heating from heat recovery systems. Modern control systems can handle machines in decentralised locations.

A centralised plant offers the advantage of a plant room environment, with lower supervision costs and simple installation. Better efficiency will come from the use of fewer, larger units, which will be more efficient and provide a better utilisation factor.

15 *Installation*

Energy can be saved by good practice in compressor installation design. The inlet air should be taken from as cool a place as possible. An increase in compressor output of 2% can be achieved by re-siting the air inlet from inside the compressor house to a cool area outside the building, and achieving a reduction in inlet temperature of 6°C. Care must be taken to ensure that air is drawn from a clean area and that the ducting employed avoids restrictions.

Compressor cooling is of the utmost importance from the energy and reliability viewpoints. If the machine is air cooled, adequate ventilation must be provided to ensure that the machine operates at its most efficient condition. If the compressor is water cooled, the water must be treated to prevent scaling or a closed circuit system must be used, and the inlet temperature must be kept at the lowest possible to maintain efficiency. The electric motors and compressor casing will radiate some heat, and adequate ventilation must be provided even when water cooling is used.

Compression of air requires a high energy input, but very little of the heat from the energy input goes forward with the compressed air. Over 90% is rejected in the cooling medium or lost through radiation.

The heat is low grade, usually being available at around 80°C, making its use difficult; however, practical recovery of 80% of the energy is possible with collection systems. Table 7 lists typical heat recovery available from air-cooled rotary screw compressors running on full load. The actual heat available will depend on the compressor load.

If ducting is used to take the air flow away from the machine, care must be taken not to restrict the cooling air stream as this will reduce the compressor efficiency. Compressor manufacturer's state a maximum length of ducting that can be used for heat recovery: if longer lengths are required, booster fans must be used to keep the air moving.

Uses for ducted hot air include space heating, air curtains and process and production applications.

Ducting should be arranged to enable hot air to be dumped during warmer periods when it is not required for space heating.

Similar savings can be achieved from water-cooled machines where the waste heat present in the cooling water discharge can be recovered. Possible uses are domestic hot water heating and raising the temperature of boiler feed and process water.

Energy saving devices which are available for air-cooled rotary screw compressors, provide hot water from the energy rejected in the oil cooler.

Very large energy savings can be made by driving compressors with engines and using the rejected heat from the engine and compressor.

Table 7 Heat recovery available from air cooled rotary screw compressors at full load

Capacity (l/s)	Nominal Motor Power (kW)	Warm Air Flow (l/s)	Heat Available (Btu/hr)	Gas Equivalent (£/annum)
40	15	450	43,382	1,249
60	22	810	71,895	2,076
159	55	1,600	182,610	5,263
314	110	3,700	365,320	10,535
450	160	5,600	535,153	15,424
585	200	8,900	671,409	19,349
725	250	8,900	840,612	24,228

7. Sources of further information

- ***British Compressed Air Society (BCAS)***

Guide to the Selection and Installation of Compressed Air Services. 4th Edition.

Copies of this Guide are available from:

BCAS
33-34 Devonshire Street
London
W1N 1RF
Tel No: 071 935 2464   Fax No: 071 935 3077

- ***British Standards***

BS 1571 Part 2: 1984 -Simplified acceptance tests for compressors and exhausters

Copies of this British Standard are available from:

British Standards Institution
Sales Department
Linford Wood
Milton Keynes
MK14 6LE

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